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B. W. Harned and M. E. Lasser 28 Oct. 1963 7p refs

October 28, 1963
(NASA Contract NASw-721)

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TO: NASA Headquarters
Washington, D. C., 20546
Attention: Code RET

SUBJECT: Theoretical and Experimental Investigation of Modulation Inducing Retrodirective Optical Systems, Contract NASw-721 (10-804) (10-1227) (Philco No. B003), Monthly Contract Progress Report No. 5, ~~for the period of~~ 21 Sep~~tember~~ 1963 ~~to~~ 21 Oct~~ober~~ 1963.

MEETINGS BETWEEN CONTRACTOR PERSONNEL AND TECHNICAL SUPERVISOR

None.

SUMMARY OF WORK ACCOMPLISHED DURING THE REPORT PERIOD

12395

The cross modulation of radiation beams has been demonstrated. The optical pumping model previously reported was incorporated in the newly constructed demonstration model. Resonance principles identical to those expected in transitions at optical frequencies are used in the cross beam which is a standard radio signal, rather than a second light beam. Construction of new light sources and an i-f exciter allowed satisfactory stability of pumping, and lead to demonstration of cross modulation with two light beams.

Cross modulation frequency response is being investigated in terms of power level, modulation frequency, and index.

Experimental investigation of the semiconductor band edge shifting technique has been started, and techniques for fabricating the materials at the doping levels and thicknesses required are being developed.

AUTHOR

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EXPERIMENTAL ACTIVITIES

As reported in the September Monthly Letter, the aim in experimental work for this period was to investigate more fully the art of producing useful light sources for optical pumping and to incorporate one such source in a demonstration model in a system which shows effective cross modulation over a range of intelligence frequencies.

It appears necessary in optical pumping to use a light source which is stable in output, with fluctuations in intensity of the pumping radiation held to a minimum. Ordinary d-c and low frequency discharges are subject to plasma oscillations, and our excitation with 27 Mc/sec electrodeless discharges also generally produced such oscillations. A model of the simple oscillator circuit recommended by Franz[1] for electrodeless excitation of small cesium bulbs at about 30 Mc/sec was constructed and found to perform in excellent fashion. A number of cesium-xenon 2.5 cm diameter bulbs were made for use with this exciter. Operation is very satisfactory at 10 watts input to the cesium source, and the undesirable oscillations are virtually eliminated.

The nature of the optical pumping alignment was discussed in the September Monthly Letter, and the means of destroying alignment in a cross modulation scheme were also mentioned. It was suggested that the low frequency Zeeman resonance lines at about 350 kc/sec would be useful for further investigation of frequency response. In view of the apparently sharp resonances at various frequencies for varying applied axial magnetic field strengths, we decided that the coincidence of resonance at standard radio broadcast frequencies for low magnetic field strengths presented the ideal demonstration technique for cross modulation effects. Therefore, apparatus was assembled to attempt to receive local radio station signals superimposed on the optical pumping light beam by means of depumping. Details of this radio receiver are shown in Figure 1.

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1. Franz, F. A., "Cs Lamp for Optical Pumping," Rev. Sci. Instr., 34, 589, 1963; Also Bell, W. E., Bloom, A. L., and Lynch, J., "Alkali Metal Vapor Spectral Lamps," Rev. Sci. Instr., 32, 688, 1961.

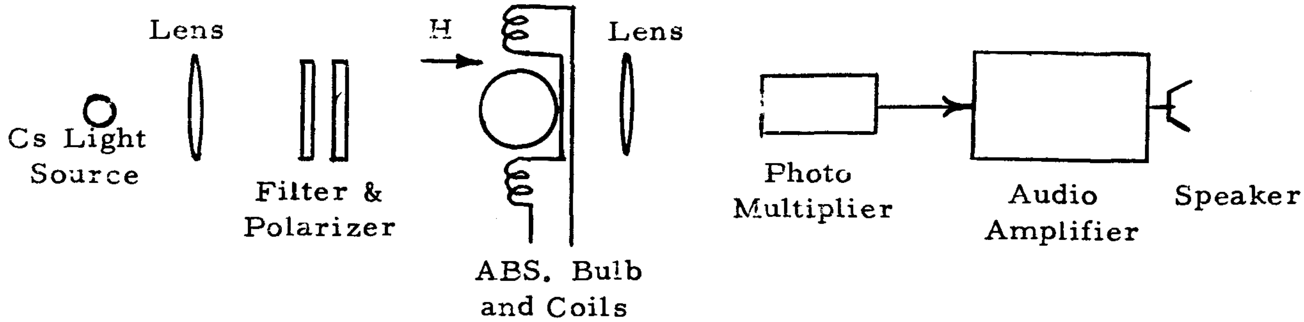

Figure 1. Radio Receiver

The only modification to the commonly reported assembly for optical pumping is the nature of the signal used to destroy orientation of the aligned atoms. The coils which produce the cross field are energized in this experiment with a signal from an intermediate frequency (450 kc/sec) amplifier stage of a standard radio receiver. The reason for using this signal, rather than that from an antenna, is that the laboratory building tends to shield against outside radiation, and the amplification of the i-f stages is necessary to increase signal strength. The resonance of the cesium between magnetic sublevels, it will be recalled, is tunable at 350 kc/sec/gauss, providing a good means of tuning this receiver. The signal appearing on the light beam is free from the carrier frequency of the audio modulation and may be fed directly into an audio amplifier.

The result of this attempt to demonstrate cross modulation was a very pleasing reception of local radio signals with amazingly good fidelity. It had been our impression from previous work with cross fields at audio frequencies that frequency response at the higher audio frequencies was very low compared with that at about 100 cps, and that the resonance width at the carrier frequency was much narrower than the frequency spread used. This fidelity has led to further investigation of response to a modulated r-f signal by means of applying a signal from an r-f signal generator which can be modulated in amplitude at various percentages, and is capable of generating an r-f signal up to 3 volts into a 50-ohm load. This signal generator has allowed us to determine frequency response of the cesium vapor near the expected resonance value which is specified by the magnitude of the applied axial magnetic field. The audio modulation frequency received by the photodetector is fed into a tuned audio amplifier. This tuned amplifier is quite useful in showing harmonic distortion of the modulation at the cesium vapor detector, and has indicated in preliminary investigation a small percentage distortion which may be power dependent. We find that the strength of the signal is reduced as we increase modulation frequency from 100 cps to 15,000 cps, but the reduction is considerably smaller than originally believed. We have also looked at frequency response by fixing modulation frequency and index and varied strength of r-f power applied to the cross field coils. In this latter case we have observed that the resonance is considerably broadened in frequency as power is increased, and the response curve tends to show one or more maxima, depending on modulation frequency. We believe this effect is caused by distortion of the axial magnetic field as cross field is increased in magnitude, and we will check it by means of a very sensitive gaussmeter. The above experimental procedure has been somewhat mechanized by driving the r-f generator with a slow speed motor and feeding appropriate signals into an X-Y recorder so that the required data may be obtained quickly and displayed and interpreted easily. Recent improvements in the optical apparatus have delayed the recording and thus reproduction of a satisfactory set of data for this report, but a complete set of curves should be available for the November letter.

There are a number of questions of an analytical nature that we believe will be partially answered by the above mentioned experimental investigation. The data of Franzen[2] for rubidium vapor spin relaxation times as a function of buffer gas pressure indicate that our neon-cesium cell should show a relaxation time of 50 to 100 milliseconds, corresponding to pumping frequencies to the very low audio range. A second cell was made in this laboratory using xenon as a buffer gas, and the data of Franzen indicate the relaxation time in this case should be of the order of one millisecond. Radio reception was possible in the second case, but at a much weaker strength than for the Ne-Cs bulb. Quantitative results on the frequency response of the second Xe-Cs bulb

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2. Franzen, W., "Spin Relaxation of Optically Aligned Rubidium Vapor," Physical Review, 115, 850, 1959.

have not yet been attempted. Earlier experiments with chopping of a cross light beam indicated results more in keeping with pumping times rather than depumping. The effect of relaxation time is therefore of very great importance in application to MIROS where two light beams are involved.

The very fine performance of the new cesium source and exciter has made it possible to perform the cross beam modulation using cesium radiation in both cases. A second exciter is being built, and means will be sought to modulate both exciters to obtain amplitude modulated light beams. The modulation impressed can be either single frequency or the multiple frequency audio range of voice or music.

Resonance between the doublet states of the cesium ground state without magnetic field splitting of the sublevels occurs at an energy corresponding to a frequency at 9.192 Gc/sec. The technique described for receiving local radio signals can be extended to this frequency range by making use of the corresponding microwave resonance frequency, rather than the magnetic sublevel resonance frequency. With an applied magnetic field, the magnetic sublevels will be separated at the specified 350 kc/sec/gauss. Resonances are still possible between sublevels of one of the doublet levels, and sublevels of the other doublet level. The only experimental difficulty is the stabilization of the modulated microwave signal generator within the resonance frequency range determined by the applied magnetic field. Equally as good fidelity of signal reception should be obtained at the higher frequency as at the radiofrequency value. Tunability of the cesium as a detector covers a wide range, as evidenced by the work of Skalinski,[3] who observed magnetic sublevel resonances at magnetic fields of 75 to 80 gauss at a frequency of 27 Mc/sec. In theory it should be possible to detect signals at extremely low strengths because of the photon multiplication nature of the resonances. Each photon at the resonance frequency produces an atom which can absorb a photon at the light frequency by the process of removing an atom from the pumped (or aligned) state to the depumped (misaligned) state. Therefore, if one is operating at the 10 to 50-microwatt level of pumping light intensities, it should be possible to detect signals at the millimicrowatt levels at microwave frequencies and micromicrowatt levels at the radio frequency resonances. In practice, this is probably difficult to achieve because of stray magnetic fields which will tend to reduce optical alignment efficiency and introduce noise.

3. Skalinski, T., "Orientation Optique des Atomes dans La Vapeur de Cesium," Le Journal de Physique et Le Radium, 19, 890, 1958.

Band Edge Shift Modulator

As mentioned previously (July 29 and August 26 Letter Reports), GaAs or InP appear to be promising materials for possible edge shift modulators using a p-n junction structure. The published data indicate that the magnitude of the effect in InP should be slightly greater than that for GaAs because of the steepness of the absorption vs energy curve at the band edge. However, we have decided to initiate experimental investigation of the edge shift effect using GaAs because the technology is more advanced. The requirements in doping level and material thickness are rather stringent, and difficulty encountered in the first fabrication attempts has prevented us from obtaining the necessary information on the modulation characteristics expected.

The Burstein shift for this type material causes the p-region to absorb radiation at lower energies than the n-region. Thus light which may be absorbed at frequencies of the absorption edge in the p-region will pass through an n-region practically completely without absorption. The modulating field should, consequently, be in the p-region, which then would have to be less heavily doped than the n-region. Doping should be light if an appreciable absorption length is to be the case. The n-region, on the other hand, should be heavily doped in order to make effective use of the Burstein shift. The partial absorption of radiation in the MIROS work calls for very thin absorbing layers, and fulfillment of the above criteria simultaneously for the n- and p-materials appears to require considerable care in selection of geometry and doping levels.

We have successfully polished a piece of GaAs to a few tenths of a mil thickness but could not handle it without breakage. Ordinarily, pieces of such material 2 mils thick are fragile and break easily. Electrolytic etching is being tried to obtain a partially supported thin layer. This technique involves directing a small stream of electrolyte directly on a sample of material which is made the anode, and etching occurs under the jet, tending to produce a hole in the sample. A mixture of 4:1 acetic and perchloric acids caused a pit with an irregular bottom, probably because of oxides which interfere with the etching. Since etching seems useful in this work, we will try modifications of the above or other solutions.

It appears that lightly diffused p-regions in n-type material should be used for this work. However, if jet etching methods can be shown to be sufficiently reproducible, it may be possible to diffuse n-type impurities into p-type bases, allowing the construction of a heavily doped n-region on a lightly doped p-type base.

PRINCIPAL INVESTIGATORS' TIME DEVOTED TO WORK

The principal investigators performing the work and the time devoted to this work by these individuals from 21 September to 21 October 1963 are as follows:

Personnel	Man-Hours
B. Harned	29
L. Leder	68
G. Racette	120

PLANS FOR THE NEXT INTERVAL

The success of the cross modulation scheme for low frequency resonances in cesium vapor indicate the need for optical frequency duplication of the experiment. The new light sources and exciters will be used for this purpose during the next period, provided that a satisfactory method of modulation of the exciters may be found. Data which are presently being taken on modulating characteristics of the vapor at low frequency will be sought for the optical frequency case. Continued effort will be applied in the band edge shift work with GaAs.

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